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Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

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SUSY searches at LHC with the CMS detector

Michele Pioppi for the CMS Collaboration

Abstract

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SUSY searches at LHC with the CMS detector

Michele Pioppi(1) on behalf of the CMS collaboration
(1) *Imperial College London, United Kingdom*

Summary. — The cascade decay of heavy supersymmetric particles is expected to produce energetic jets, missing transverse momentum and leptons. A selection of the search strategies employed in CMS are described and the results obtained with the 35 pb^{-1} of data recorded in 2010 are presented. The data did not show any significant deviation with respect the expectation from Standard Model processes. The limits on the existence of supersymmetric particles set by TeVatron and LEP experiments are abundantly extended.

PACS `12.60.Jv` – supersymmetric models.

1. – Introduction

The standard model (SM) of particle physics has been enormously successful in describing all phenomena at the highest attainable energies thus far. Yet, it is widely believed to be only an effective description of a more complete theory which is valid at the highest energy scales. Of particular theoretical interest is SuperSymmetry (SUSY) [1, 2] which solves the hierarchy problem of the SM by compensating for each of the fermionic and bosonic degrees of freedom in the SM with a supersymmetric bosonic and fermionic degree of freedom, respectively. The resulting superfields have the same quantum numbers as their SM counterparts, except for spin. Since no SUSY particle has been observed so far, they must have higher masses than their SM partners, implying that SUSY is a broken symmetry. At the Large Hadron Collider (LHC) at CERN, supersymmetric particles, if they exist, are predicted to be produced dominantly via QCD, through the fusion of two gluons into a pair of gluinos, a pair of squarks, or a gluino and a squark.

The LHC, with a proton-proton $\sqrt{s} = 7$ TeV, is a copious source of high-energy partons which allows to probe squark and gluino masses beyond the limits previously set at LEP and at the TeVatron. Squarks and gluinos initiate a decay cascade in which quarks, leptons and photons are produced, until the lightest supersymmetric particle (LSP) is created. The dynamics of the cascade depends on the SUSY model under consideration, and in particular on the masses of the supersymmetric particles.

In these proceedings, the emphasis is put on the search for SUSY in final states fully hadronic, with two leptons with the same sign and with two photons. The results presented in these proceedings are based on the data collected by the CMS experiment [3] in 2010 (~ 35 pb^{-1})

2. – Search for SuperSymmetry in All-Hadronic final state

In the decay of gluinos and squarks there is an abundant productions of hadronic jets while the presence of leptons and photons is not guaranteed, thus the production of all hadronic final states is the most frequent final state deriving from Susy particles. In CMS, three complementary approaches are followed. The jets + Missing Energy analysis, described elsewhere [4], consists of looking for an excess of multi-jet events at high Missing Energy. This approach is the most efficient of the three, but requires the QCD background to be accurately controlled. The razor analysis [5] relies on the kinematical properties of the production of two heavy particles. A third method based on the kinematical properties of the QCD background [6] has been developed. With respect the other two approaches, this analysis is very robust against jet energy mis-measurement which is the most important source of fake missing transverse energy. The data sample used in this analysis is recorded using a trigger based on the scalar sum (HT) of the transverse energy (E_{T}) of jets reconstructed at the trigger level. The pseudo-rapidity of the leading jet is required to be within $|\eta| < 2.5$ and the transverse energies of each of the two leading jets must exceed 100 GeV. Events with isolated photon with $P_{\mathrm{T}} > 25$ GeV or isolated leptons (electron or muon) with transverse $P_{\mathrm{T}} > 10$ GeV are vetoed. Jet mis-measurements are potentially the dominant source of (fake) missing transverse energy in the events from the QCD background. To control this background and to separate it from a genuine missing energy signal, a variable which is robust against energy mis-measurements, $\alpha_T = E_{\mathrm{T}}^{\mathrm{j}_2}/M_{\mathrm{T}}$ [7], is used. For events with two jets, $E_{\mathrm{T}}^{\mathrm{j}_2}$ is the transverse energy of the jet with the lower E_{T} in the event and M_{T} is the transverse mass of the di-jet system. For a perfectly-measured di-jet event, with $E_{\mathrm{T}}^{\mathrm{j}_1} = E_{\mathrm{T}}^{\mathrm{j}_2}$ and jets back-to-back in ϕ, and in the limit where the jet momenta are large compared to their masses, the value of α_T is nearly 0.5 (Fig. 1 left). In case of an imbalance of the measured transverse energies, α_T takes on values < 0.5. For larger jet multiplicities, the n-jet system is reduced to a di-jet system by combining the jets in the event into two pseudo-jets. The chosen combination is the one which minimizes the E_{T} difference of the two pseudo-jets. To protect against multiple jets failing the > 50 GeV threshold, the jet-based estimate of the missing energy, $MHT = | - \sum_{\mathrm{jets}} \vec{P}_{\mathrm{Tjets}}|$, is compared to the calorimeter tower-based estimate of the missing energy, E_{T}^{miss}, and events with $MHT/E_{\mathrm{T}}^{miss} > 1.25$ are rejected. In the signal region (HT $>$ 350 GeV) 13 events pass the requirements. The total background is estimated with the ratio of the numbers of events which pass and fail the α_T selection requirement (R_{α_T}). The total number of background events with $\alpha_T > 0.55$ from SM processes in the signal region is therefore the product of the extrapolated R_{α_T} in the signal region with the number of events with $\alpha_T < 0.55$ and $HT > 350$ GeV. This estimate ($9.4^{+4.8}_{-4.0}$ (stat) ± 1.0 (syst)) is found to be compatible with the observed number of events in data after the full cut-flow. An upper limit on the number of non-SM events compatible with the measurements is derived in this section using the Profile Likelihood method. To interpret the consistency of the observed number of events with the background expectation in the context of a model, and also to facilitate comparison with previous experimental results, an exclusion limit in the CMSSM [8] is set. The 95% CL limit for $\tan\beta = 3$ and $A_0 = 0$ is shown in Fig. 1 (right) and the excluded region significantly extends the previous limits from TeVatron and LEP experiments.

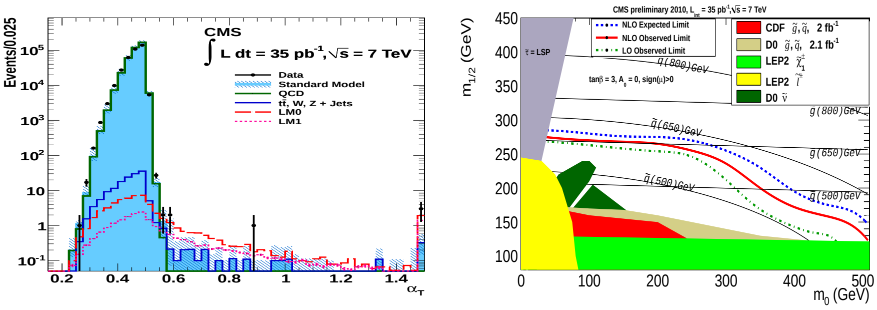

Fig. 1. – Left:α_T distribution in data and simulation for events with only 2 reconstructed jets. Right: 95% CL exclusion contour at NLO in the CMSSM $(m_0, m_{1/2})$ plane ($\tan\beta = 3$, $A_0 = 0$ GeV, $sign(\mu) > 0$).

3. – Search for SuperSymmetry in Same Sign Di-Lepton final state

Same-sign isolated lepton-pairs are very rare in the Standard Model (SM) but appear very naturally in many supersymmetric scenarios [9, 10, 11]. In order to maximize the sensitivity to the presence of new physics from SUSY, four different search regions are defined [13]: 1) HT >200 GeV, $E_{\mathrm{T}}^{miss} > 30$ GeV, $\ell_1 > 20$ GeV, $\ell_2 > 10$ GeV with $\ell_1, 2 = e, \mu$, 2) HT > 60 GeV, $E_{\mathrm{T}}^{miss} > 80$ GeV, $\ell_1 > 20$ GeV, $\ell_2 > 10$ GeV with $\ell_1, 2 = e, \mu$, 3) HT >300 GeV, $E_{\mathrm{T}}^{miss} > 30$ GeV, e >10 GeV, $\mu > 5$ GeV, 4) HT >350 GeV, $E_{\mathrm{T}}^{miss} > 50$ GeV, e >10 GeV, $\mu > 5$ GeV, $\tau > 15$ GeV. The first two search regions are selected with single electron/muon triggers while the last two regions are selected with a pure HT trigger that allows to explore the phase space of low-P_{T} electrons and muons, as well as final states with hadronic τ decays. In all the regions both the leptons must be isolated. Backgrounds in all of our searches are dominated by one or two jets mimicking the lepton signature. Such lepton candidates can be real leptons from heavy flavor decay, electrons from unidentified photon conversions, muons from meson decays-in-flight, hadrons reconstructed as leptons, or jet fluctuations leading to hadronic τ signatures. Backgrounds from jets mimicking leptons are estimated using the so-called “Tight-Loose” (TL) method [12]. In this method a probability, for a lepton passing loose cuts to also pass the tight analysis cuts is measured in QCD multi-jet events. To predict the background from real lepton + jets in a signal region, the TL probability is applied to a sample of di-lepton events satisfying all requirements but where one of the leptons fails the tight cuts and passes the loose cuts. A second potentially important source of background consists of opposite-sign di-lepton events where the sign of the charge of one of the electrons is mis-measured because of hard bremsstrahlung in the tracker volume. The probability of mis-measuring the charge of the electron is obtained in data by selecting a sample of $Z \to ee$ events. The background due to charge mis-identification is estimated by scaling the opposite-sign yields by the above probability. Fig. 2(left) summarizes the signal region yields and background composition in all four search regions Estimates for backgrounds due to events with one or two fake leptons and from electron charge mis-measurement were obtained directly from data in appropriately chosen control regions. The remaining irreducible background from two real same-sign leptons (WZ, ZZ, $t\bar{t}W$, etc.) amounts to at most 10% of the total and is estimated based on theoretical cross section predictions and Monte Carlo simulation. No evidence of an event yield in excess of the background prediction is observed and a 95% CL upper limits are set on the number of observed events using a Bayesian method with a flat prior on signal strength and lognormal for efficiency and background uncertainties. The absence of new physics is interpreted in the CMSSM model (Fig. 2 right).

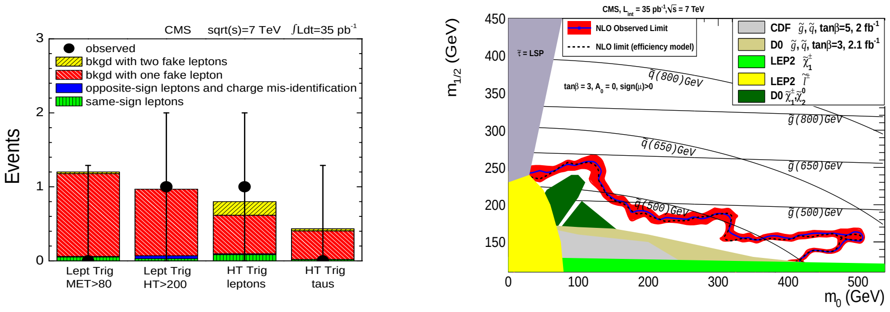

Fig. 2. – Left:Number of expected and observed events in the 4 search regions defined to search SUSY in the same sign di-lepton final state. Right: Exclusion contour in the m_0 - $m_{1/2}$ plane for CMSSM.

4. – Search for SuperSymmetry in Di-Photon + Missing Energy final state

One of the well-established scenarios for physics beyond the Standard Model is General Gauge-Mediation (GGM) SUSY [14, 15], with the gravitino as the lightest SUSY particle (LSP) and the lightest neutralino as the next-to-lightest (NLSP). The latter promptly decays into a photon and a gravitino, which escapes detection, leading to apparent E_{T}^{miss}. If R-parity is conserved, strongly-charged SUSY particles are pair-produced, resulting in the presence of two neutralinos and multiple jets per event. The topology of interest for this search [16] is, therefore, two isolated high E_T photons, at least one hadronic jet, and E_{T}^{miss}. Photon candidates are required to be isolated and to have $E_T \geq 30$ GeV and $|\eta| \leq 1.4$. At least one jet with $E_{\mathrm{T}} > 30$ GeV and $E_{\mathrm{T}}^{miss} > 50$ GeV is required.

The SUSY signal can be mimicked in several ways. The dominant contribution comes from mis-measurement of E_{T}^{miss} in QCD processes such as direct di-photon, photon plus jets, and multi-jet production, with jets mimicking photons in the latter two cases (QCD background). The strategy for determining this background is to use control samples which are kinematically similar to the candidate sample while having no real E_{T}^{miss}. The control sample contains events with two electrons with invariant mass between 70 and 110 GeV, and is dominated by the $Z \rightarrow ee$ decays.

The second background comes from events with real E_{T}^{miss}. It is dominated by the events with a real or fake photon and a W that decays into a neutrino and an electron, with the latter mis-identified as a photon (EWK background). Since all components of this background involve electron-photon mis-identification, in order to estimate its contribution to the signal sample, we weight the eγ sample with $f_{e\rightarrow\gamma}/(1 - f_{e\rightarrow\gamma})$ where $f_{e\rightarrow\gamma}$ is the probability to mis-identify an electron as a photon. Fig. 3 (left) shows the E_{T}^{miss} distribution for the selected events and the expected background. Only 1 event is observed in the region with $E_{\mathrm{T}}^{miss} \geq 50$ and the predicted background is 1.2±0.8 Based on the probability to observe zero or one event at the predicted signal cross section, the

95% CL exclusion regions shown in Fig. 3(right) for GGM SUSY is determined in the squark-gluino mass plane for various choices of the $\tilde{\chi}_1^0$ neutralino mass.

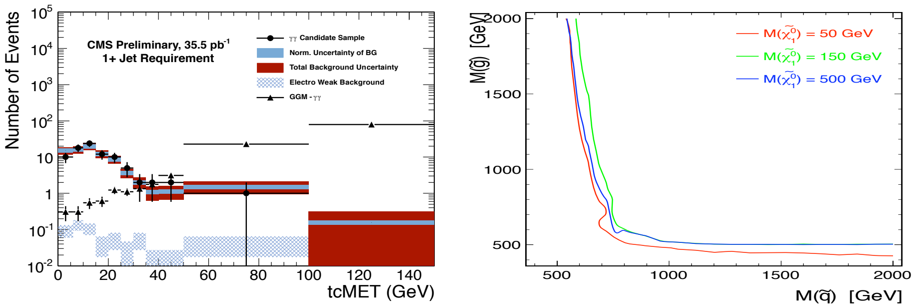

Fig. 3. – Left: Observed and expected from SM background E_{T}^{miss} distribution. Right: Exclusion contour in the m_g - $m_{\tilde{q}}$ plane for various choices of the neutralino mass.

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